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USE OF LANDSAT IMAGES OF VEGETATION COVER TO ESTIMATE EFFECTIVE HYDRAULIC PROPERTIES OF SOILS

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Final Technical Report

On NAG 5–510

The estimation of the spatially variable surface moisture and heat fluxes of natural, semivegetated landscapes is difficult due to the highly random nature of the vegetation (e.g., plant species, density, and stress) and the soil (e.g., moisture content, and soil hydraulic conductivity). The solution to that problem lies, in part, in the use of satellite remotely sensed data, and in the interpretation of those data in terms of the physical properties of the plant and soil.

This work has focused on the development and testing of a stochastic geometric canopy–soil reflectance model, which can be applied to the physically–based interpretation of Landsat images. The model conceptualizes the landscape as a stochastic surface with bulk plant and soil reflectance properties. The model is particularly suited for regional scale investigations where the quantification of the bulk landscape properties, such as fractional vegetation cover, is important on a pixel by pixel basis. A summary of the theoretical analyses and the preliminary testing of the model with actual aerial radiometric data is provided below.

Theoretical Analysis

Theoretical analysis has included (i) an investigation of the relation between the shape of red–infrared scattergrams and the physical structure of the scene and (ii) the development of a methodology, based on (i), for the retrieval of subpixel properties. That work was previously reported (Eagleson and Jasinski, 1988) and is only summarized below.

The information content of red–infrared scattergrams was investigated through the simulation of a series of scenes of varying complexity. The role of several variables was determined by sequentially introducing them into the scene, and

observing their individual corresponding effect on the scattergram. In particular, that analysis led to an understanding of several principal mechanisms which contribute to the often observed triangular shape, or "tasseled cap" of typical red–infrared scattergrams. They included (i) variable vegetation density, (ii) variable soil background reflectance, and (iii) the covariance between vegetation cover and shadow which exists, especially when the scale of the pixel is large compared to the length scale of the shadow. The details of the above theoretical analyses are summarized in the appended report (updated version, sent to IEEE Transactions on Geoscience and Remote Sensing, October, 1988).

It was also demonstrated that the fractional (i.e. subpixel) vegetation cover of the simulated scenes can be retrieved by applying the method of moments to the red–infrared scattergram of the aggregated scene. The method consists of equating the theoretical moments of the canopy–soil reflectance to the actual moments of the scene, and then solving for the unknown variables. At least seven moment equations can be written for the reflectance model, including five reflectance moments (i.e., the mean and variance of the reflectance equation in the red and infrared bands, and the cross–covariance) and two cover moments (i.e., the mean and variance). Conditional moments can also be written through the *a priori* understanding of the structure of the red–infrared scattergram. For instance, the means and variances of the soil reflectance terms can be written for the locus of pixels which constitute the soil line.

The inverse problem was applied to two test cases. For the Case II simulation (referred to in the appended report), the fractional vegetation cover was estimated by writing conditional moment equations along lines parallel to the soil line, as shown in the scattergram in Figure 1. For the Case V simulation, the analysis includes the writing of conditional moments for statistically homogeneous areas as shown in Figure 2. Comparisons of the estimated and actual mean vegetation cover

for a range of cover types are provided in Figures 3 and 4, respectively. Results indicate very good agreement. Details of these results are currently being summarized for publication in an appropriate journal.

The stochastic canopy–soil reflectance model has also provided a mechanism for studying the influence of scene variability on common vegetation indices, such as the normalized vegetation index (NVI). One important conclusion of that study is that the maximum NVI of a scene does not necessarily represent maximum vegetation amount, but it is affected by both shadows and soil variability. A third journal article detailing those results will be completed shortly.

Model Testing

The canopy model was tested on a Pecan orchard for which aerial radiometric observations and corresponding ground truth were obtained. The orchard is located near Maricopa, Arizona, about 40 km south of Phoenix. Aerial radiometric measurements were collected on June 12, 1988, in conjunction with the MAC III experiment organized by the Water Conservation Laboratory, Agricultural Research Service, Phoenix, Arizona. Radiometric observations were made using an Exotech radiometer with Thematic Mapper red (0.62–0.69 μm) and IR (0.78–0.90 μm) filters at a ground resolution of about 40 meters.

Model testing consisted of comparing the plots of the actual radiometric data in the red–infrared reflectance space, with the hypothetical scattergram constructed from ground truth measurements taken at the time of overflight. Construction of the hypothetical scattergram required the development of the appropriate analytical relationships among canopy cover, shadowed soil, and illuminated soil (Figure 13 of appended report). The good agreement between the actual radiometric data and the hypothetical scattergram (Figure 14 of appended report) provides preliminary confirmation of the validity of the stochastic model for explaining the structure of

red–infrared scattergrams. Details of the above work are also provided in the appended report.

Two additional data sets were acquired as part of the present study. The first is a set of aerial radiometric data taken in June 1988 over three specified watersheds in the Beaver Creek Basin of the Coconino National Forest in Northern Arizona. Second, a geocoded Landsat Thematic Mapper scene was purchased over the same region in Northern Arizona. Testing of the canopy–soil model on those two data sets is currently under way under separate support.

Hypotheses Testing.

Most of the climatological, hydrological, and soils data required to test Eagleson's climate–soil–vegetation equilibrium hypotheses have been obtained for the Beaver Creek Basin in northern Arizona. Testing has begun but its conclusion awaits continued NASA support.

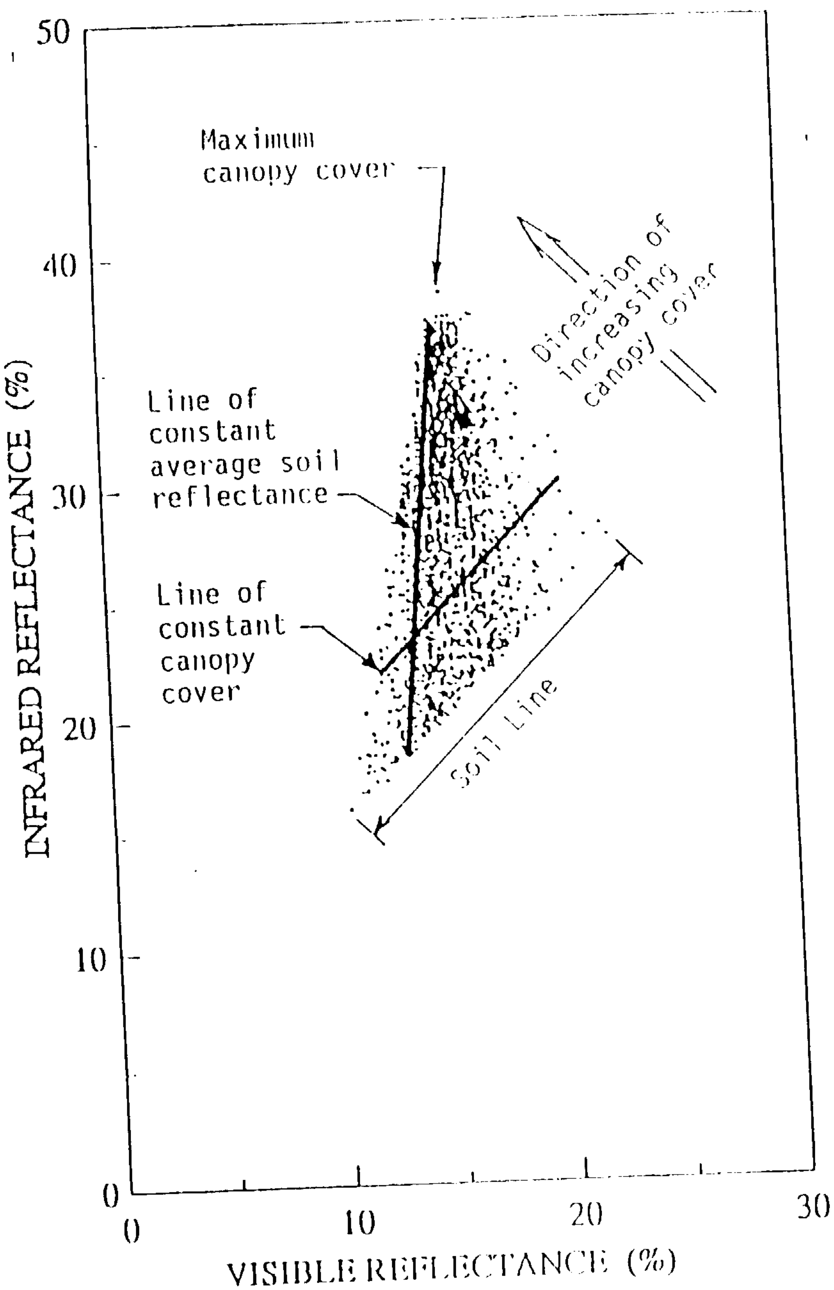
Publications

Eagleson, P. S. and M. F. Jasinski, "Use of Landsat Images of Vegetation Cover to Estimate Effective Hydraulic Properties of Soils." Final Technical Report, NAG 5-510. 1 August 1988.

Jasinski, M. F. and P. S. Eagleson, "The Structure of Visible-Infrared Scattergrams of Semivegetated Landscapes," submitted to IEEE Transactions on Geoscience and Remote Sensing. February, 1988.

Jasinski, M. F. and P. S. Eagleson, "Estimation of Subpixel Vegetation Cover Using Red-Infrared Scattergrams." In preparation.

Jasinski, M. F. and P. S. Eagleson, "The Physical Basis of Common Vegetation Indices for Semivegetated Landscapes." In preparation.



EXAMPLE CASE:

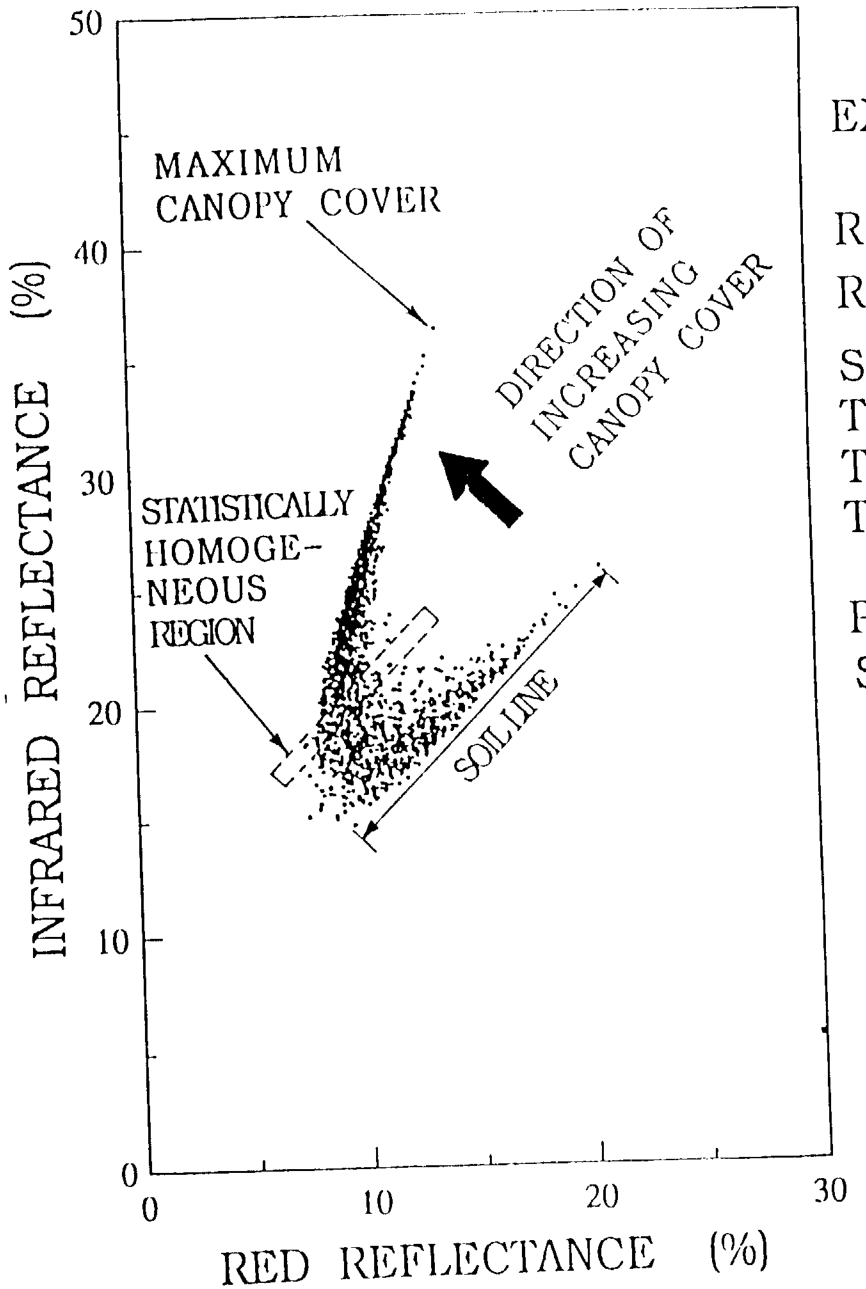
R_{VEG}'s constant
R_{SOIL}'s variable
Solar Zenith Angle = 30^0
Tree Height = 5 m.
Tree Canopy Area = 1 sq. m.
Tree Location: Poisson Distribution with variable rate

Pixel Area = 10 x10 = 100 sq. m.
No Shadows

Figure 1

Red – Infrared Scattergram

Case II Simulation



EXAMPLE CASE:

R_{VEG}'s constant
R_{SOIL}'s variable
Solar Zenith Angle = 30^0
Tree Height = 5 m.
Tree Canopy Area = 1 sq. m.
Tree Location: Poisson Distribution with variable rate

Pixel Area = 10 x10 = 100 sq. m.
Shadows

Figure 2

Red – Infrared Scattergram

Case V Simulation

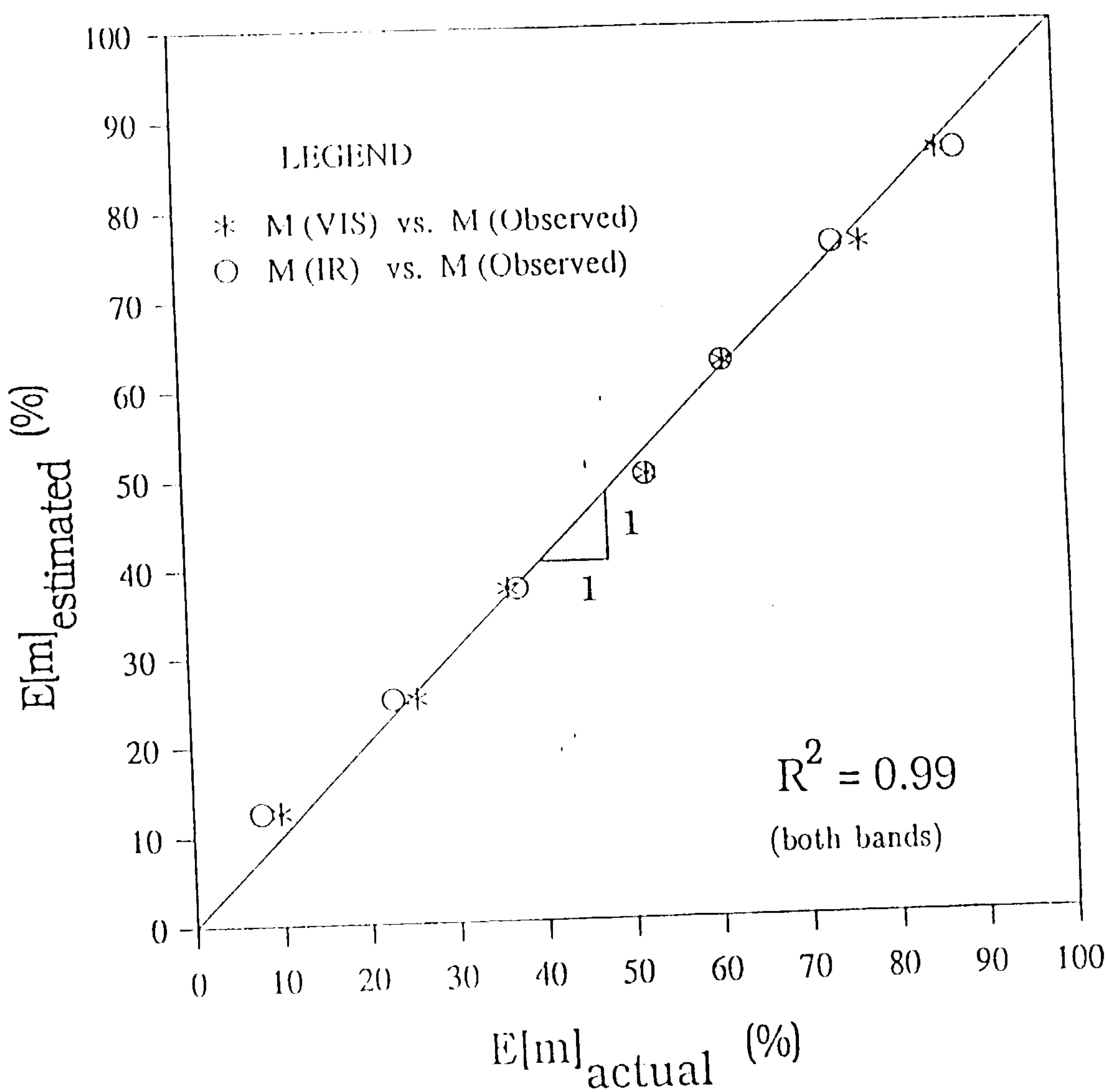


Figure 3. Estimated vs. Actual Mean Subpixel Canopy Cover

Case II Simulation

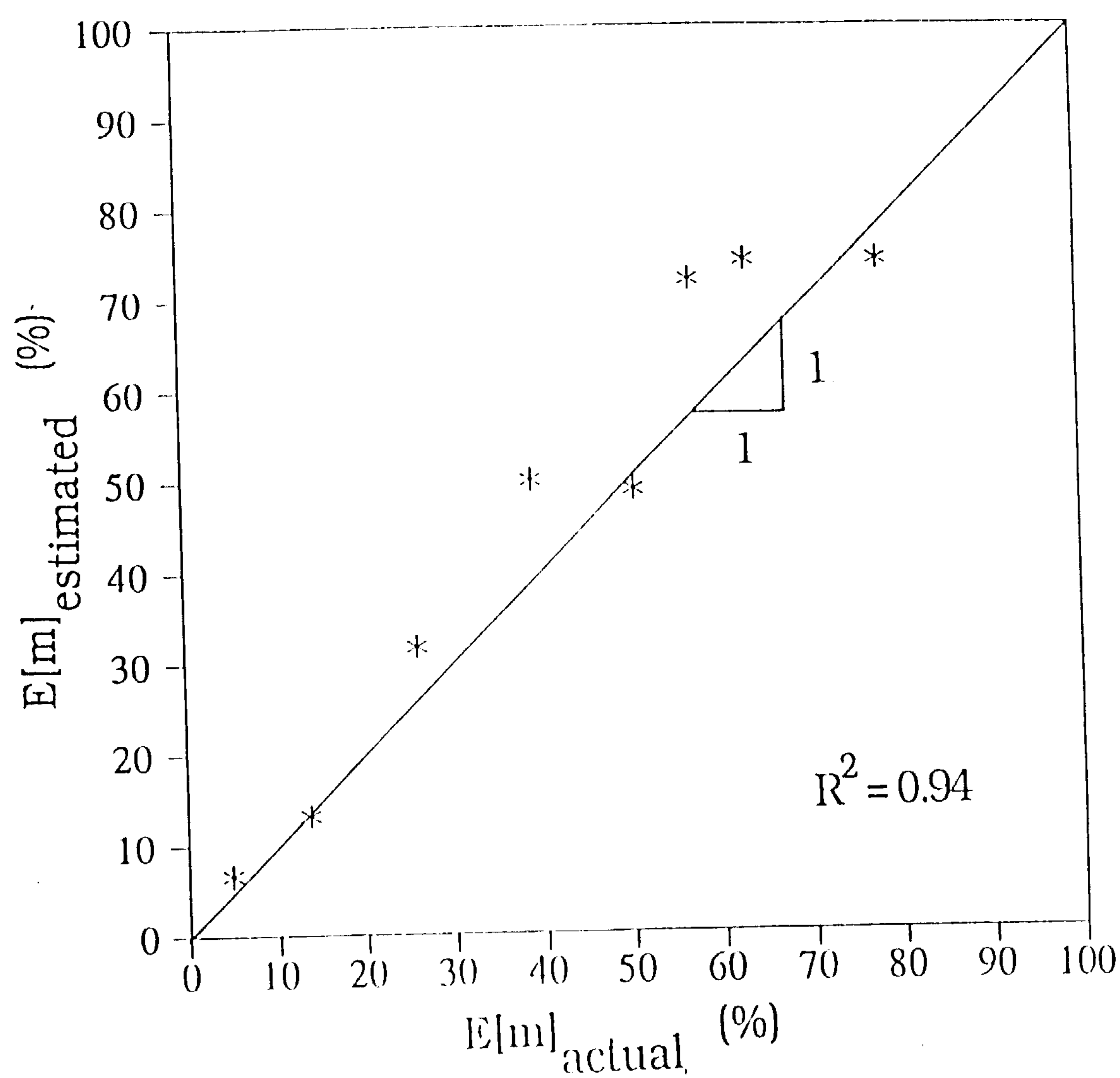


Figure 4. Estimated vs. Actual Mean Subpixel Canopy Cover

Case V Simulation